

Composite Materials for Wind Blades: Current Performance and Future Directions



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Fiber Glass and Coatings
for Wind Power

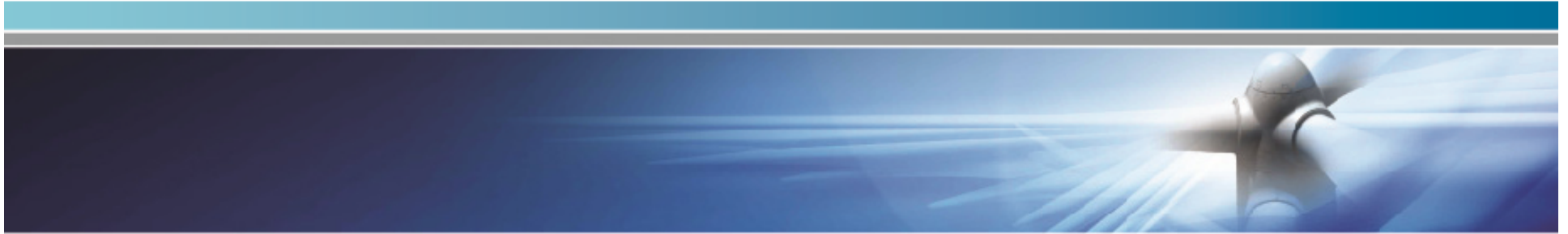


Sandia National Laboratories · 2010 Wind Turbine Blade Workshop · July 20-21 2010
Presented by Juan Camilo Serrano · PPG Industries Inc.



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OUTLINE



1. PPG Wind Energy
2. Evolution of wind blade materials
3. The current state –performance review
4. Alternatives for stronger, stiffer blades
5. The future state - long term goals and new developments



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PPG Wind Energy

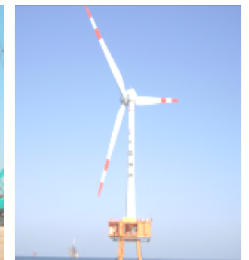
1. PPG Wind Energy

- Offering a multitude of products for wind turbines

- Fiber glass for blades, nacelles
- Coatings for blades, towers

- World leader in fiber glass

- Established in wind energy for 15+ years
- Production and sales from 3 major continents
- Hybon® 2002/2001 recognized product in wind energy blades
 - Specified in blades from most major manufacturers around the world
- Continuing to develop new products that will enhance wind energy production for the future





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PPG Wind Energy Fiber Glass Product History

1. PPG Wind Energy

Hybon® 2002/2001

- Specified and used at most wind turbine companies
- Designed for multiple resin compatibility

Hybon® 2026

- Multiple resin compatibility
- Enhanced processing characteristics
- Improved strength and fatigue life

	Tensile Strength	Flexural Strength	Short Beam Shear Strength	FWF
Units	MPa	MPa	MPa	%
Method	ISO 527-5	ISO 14125	ISO 14130	
Sample Prep	A	A	B	
Hybon® 2002	1107	1221	64	74.8
Hybon® 2026	1148	1339	67	75.6

A – Unidirectional infused panels, Hexion RIM 135 epoxy
B - Filament wound cylinders per ASTM D 2291

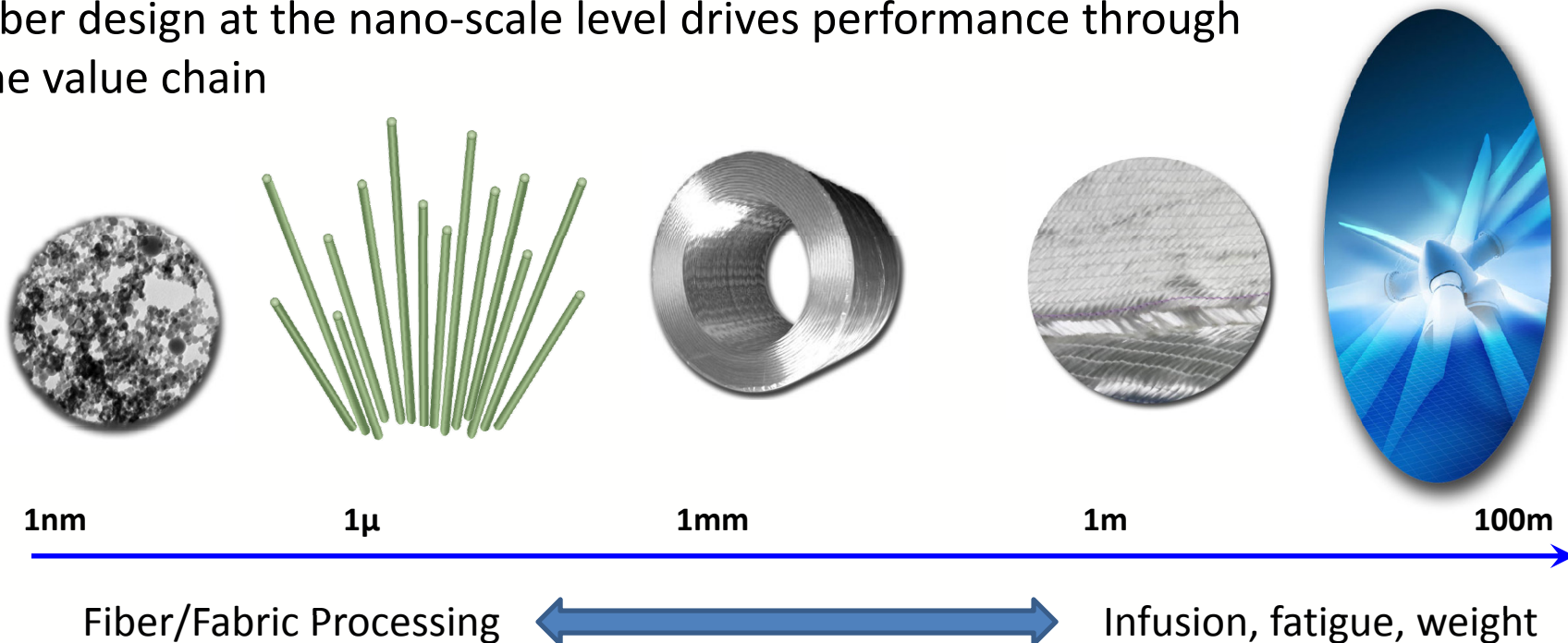


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Blade Performance Nano scale to Mega Watt

1. PPG Wind Energy

Fiber design at the nano-scale level drives performance through the value chain





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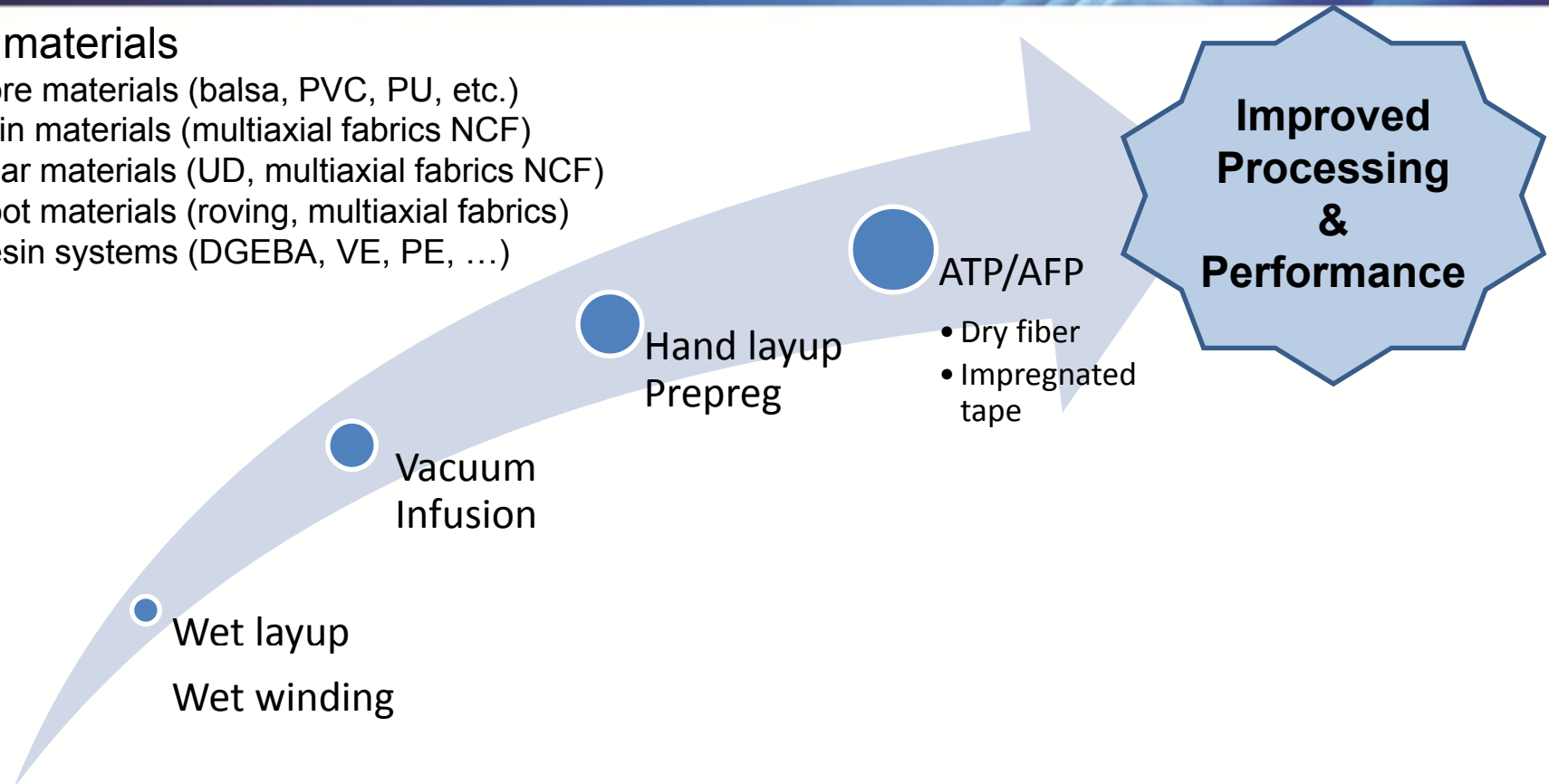


Evolution of wind turbine blade production

2. Evolution of wind blade materials

Input materials

- Core materials (balsa, PVC, PU, etc.)
- Skin materials (multiaxial fabrics NCF)
- Spar materials (UD, multiaxial fabrics NCF)
- Root materials (roving, multiaxial fabrics)
- Resin systems (DGEBA, VE, PE, ...)





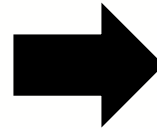
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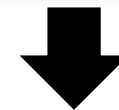
Performance review

3. The current state – performance review

- SNL/MSU/DOE database
- Optidat Database
- PPG internal test data
- Other public information



PPG / DOE database



Static
Properties

Fatigue
Properties



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Material forms

3. The current state – performance review

- Prepreg based materials
 - UD, Biax
- Infusion grade materials
 - UD, Biax, Triax

APPLICATION/ REINFORCEMENT	UD	BIAX 0/90 – 45	TRIAX	ROVING
WEB				
SPARCAP				
SKIN				
ROOT				



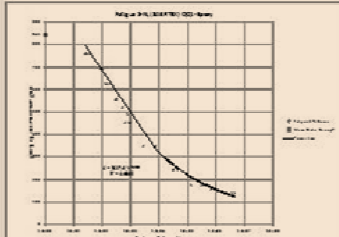
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Electronic Database

WIND PPG/DOE DATABASE

WIND PPG/DOE DATABASE

ID:	16	Tensile strength 90:	149
Company:	SAERTEX	Tensile modulus 90:	17.1
process:	Infusion	Compressive strength 90:	274
fiber:	Glass	Shear strength:	
RESIN:	Epoxy	Shear modulus:	
designation:	QQ1 (ID 7 & ID 10)	FWF:	
sample ID:	9281-9313 9314-9832	FVF:	53
Application:	SPAR	R:	0.1
FAW:	1786	Frequency:	
layup:	[+45/(0)2]s	Cycles to failure:	
Tensile strength 0:	843	S-N Curve:	
Tensile modulus 0:	33.1		
Compressive strength 0:	687		

Record: 14 16 of 23 No Filter Search

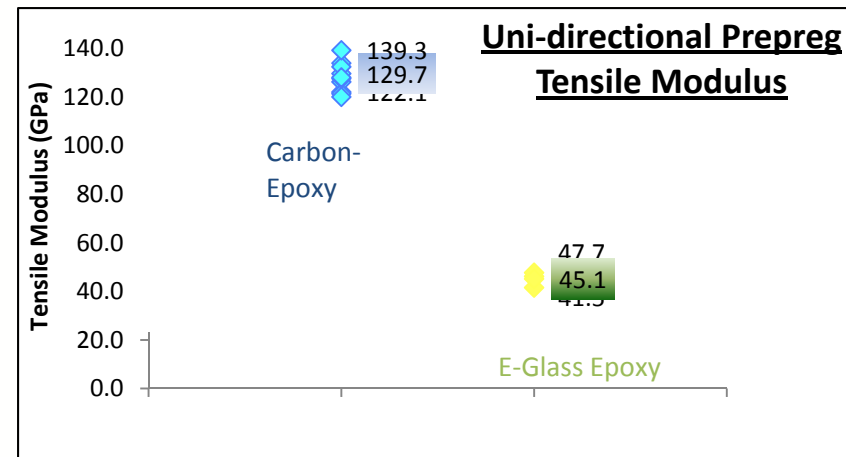
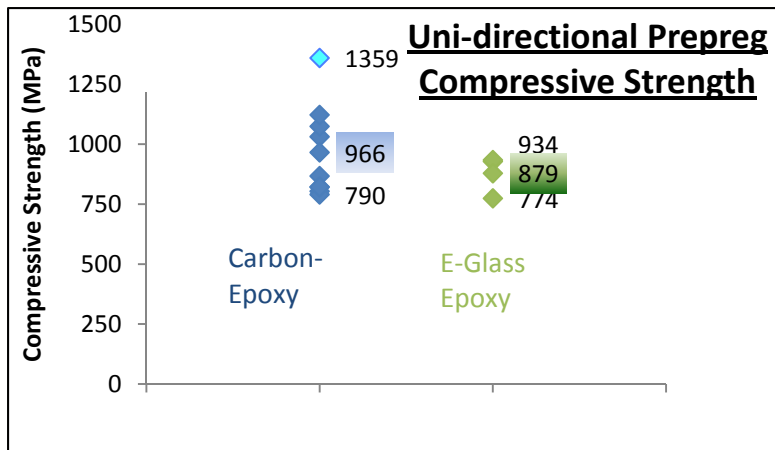
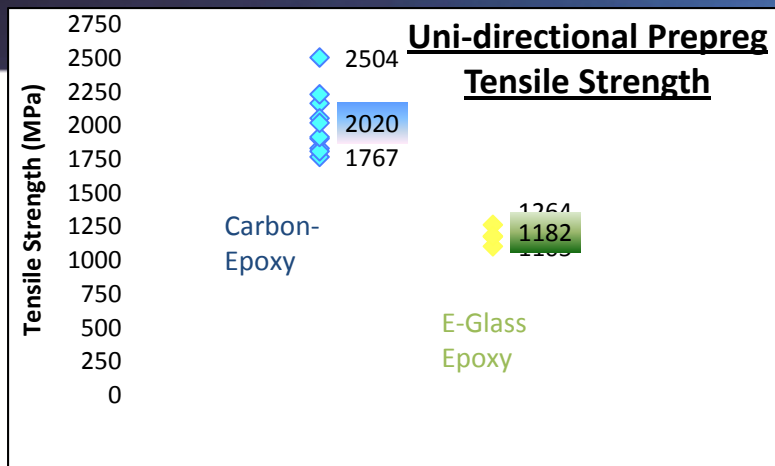


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UD Prepreg Static Properties

3. The current state – performance review



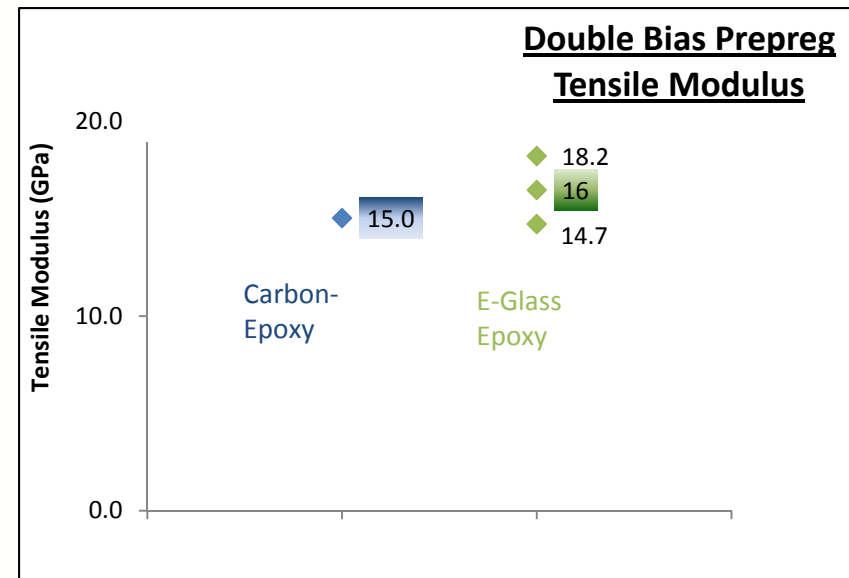
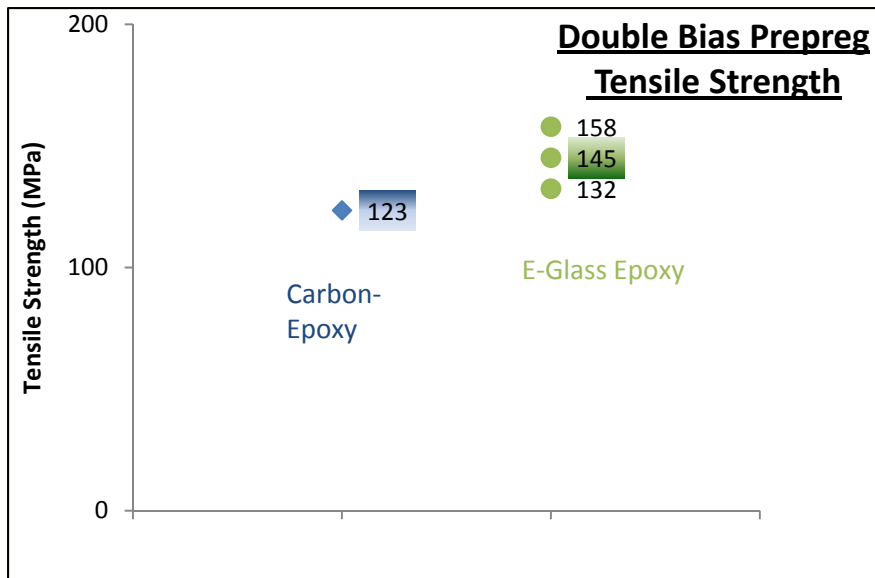


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Double bias Prepreg Static Properties

3. The current state – performance review



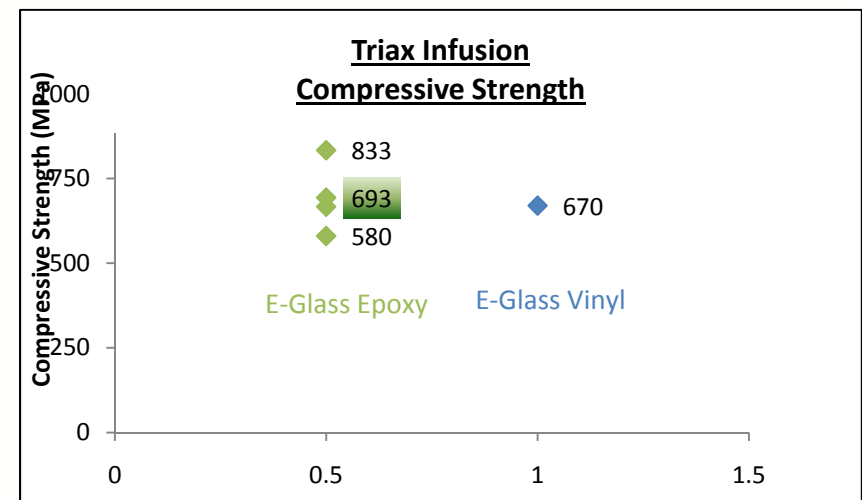
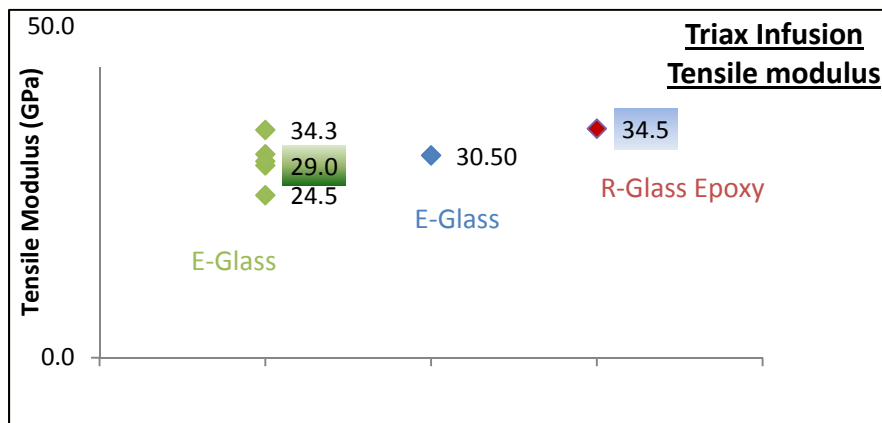
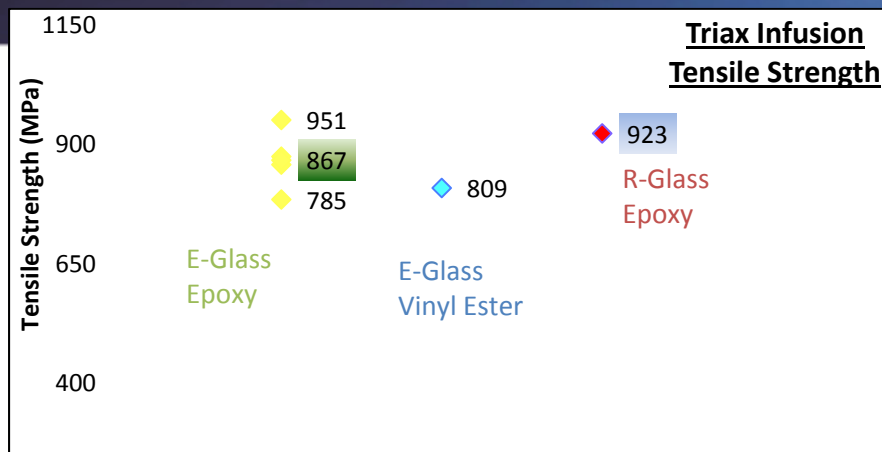


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Triaxial Infusion Static Properties

3. The current state – performance review



How to drive performance?

4. Alternatives for stronger, stiffer blades

1. Design/Geometrical approach (Increase Moment of Inertia – stiffness)
2. **Material performance enhancements (strength and/or stiffness)**
 1. Sizing Chemistry (strength)
 2. Fiber Composition (strength + stiffness)
 3. Fiber Volume Fraction (strength + stiffness)
 4. Defect reduction/prevention (strength*)

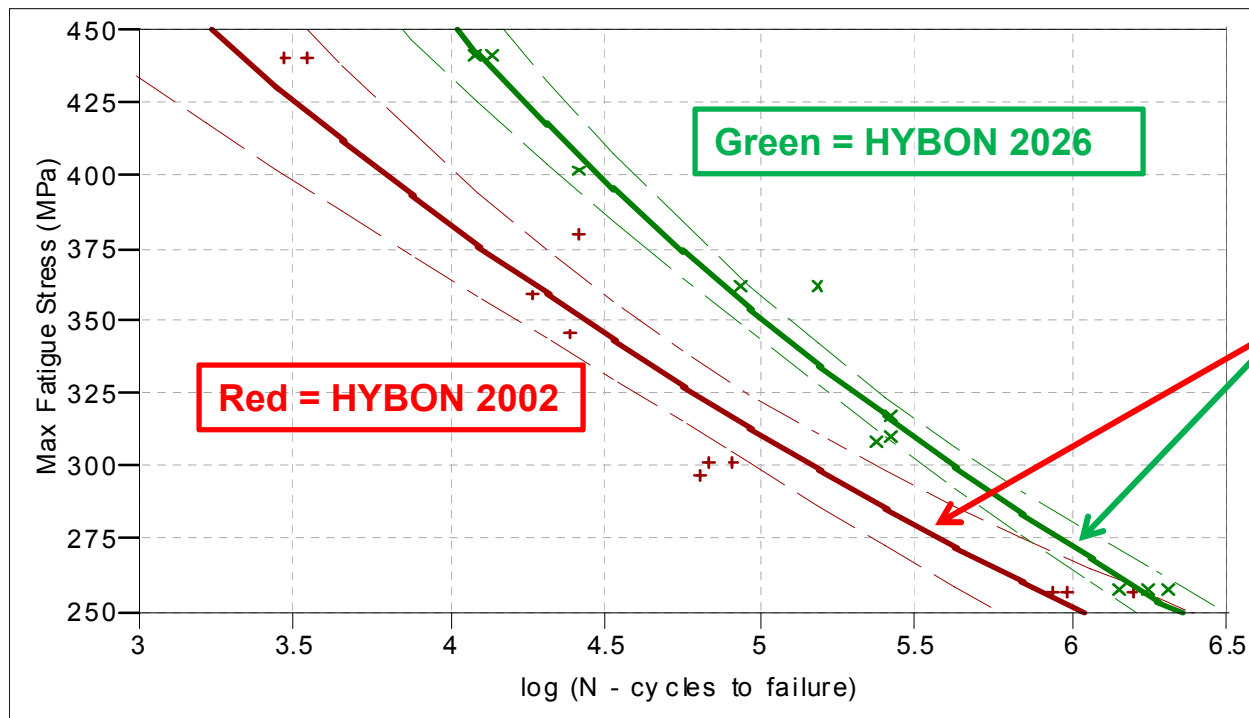
*at component level



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Sizing Chemistry

4. Alternatives for stronger, stiffer blades: Sizing Chemistry



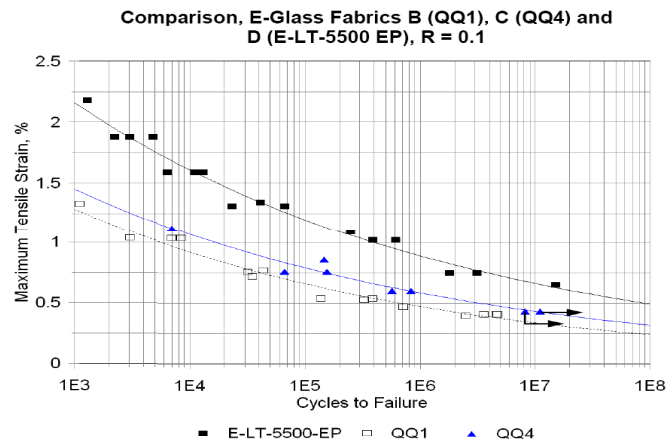
~10 % Improvement
~2x on absolute scale



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Sizing Chemistry

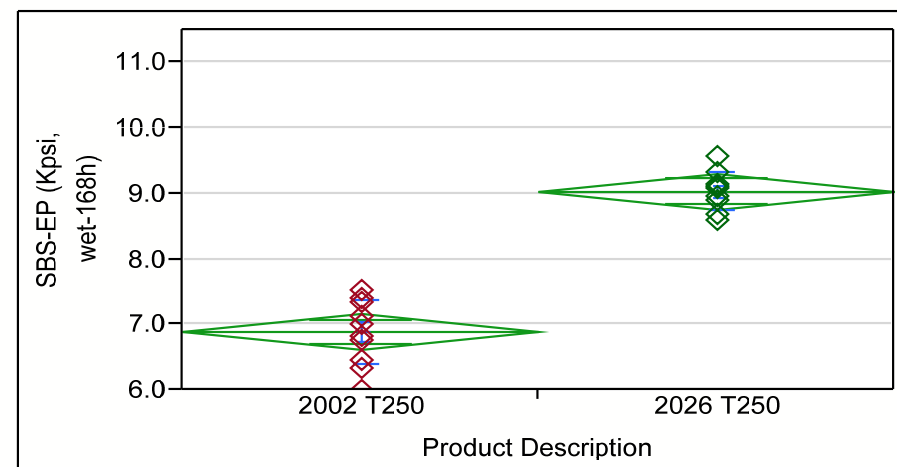
4. Alternatives for stronger, stiffer blades: Sizing Chemistry



Resin: EP = EPON 826
Method: SBS = ASTM D2344
All testing on 1984 TEX (250 Yield) rovings

Montana State results

- Vectorply E-LT 5500 using Hybon® 2026 4400TEX input in zero direction
- Supports value of Hybon® 2026



4. Alternatives for stronger, stiffer blades: Increase FVF

Advantages:

- Avenue for increasing spar cap stiffness (reduction in tip deflection)
- Achievable with existing materials

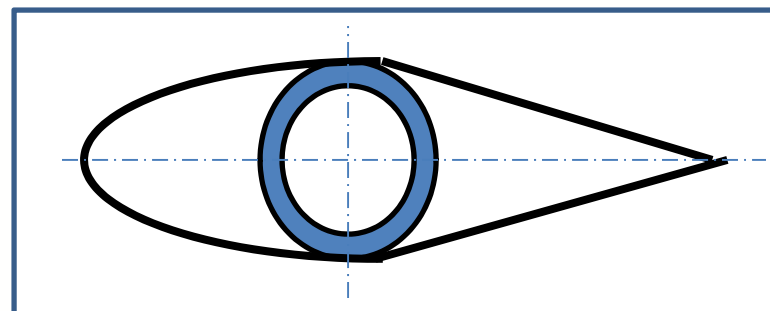
Disadvantages:

- Effect on long term performance of composite laminate (fatigue)?
- Increase in weight
- Difficulties in processing (dry spots)

Hypothetical case FVF

4. Alternatives for stronger, stiffer blades: Increase FVF

- Circular cross section spar
- Parameters include
 - Outside Diameter (OD), Inside Diameter (ID)
 - Spar length (L)
 - Elastic Modulus of Fiber (E_f)
 - Fiber Volume Fraction (FVF)



OD = 0.6 m, ID = 0.55 m

L = 60 m

E_f = 79 GPa (Impregnated strand tensile)

FVF = 50%

Modulus translation efficiency = 97%

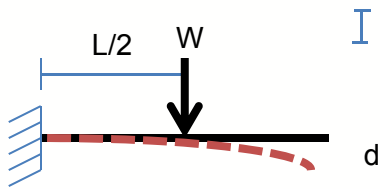
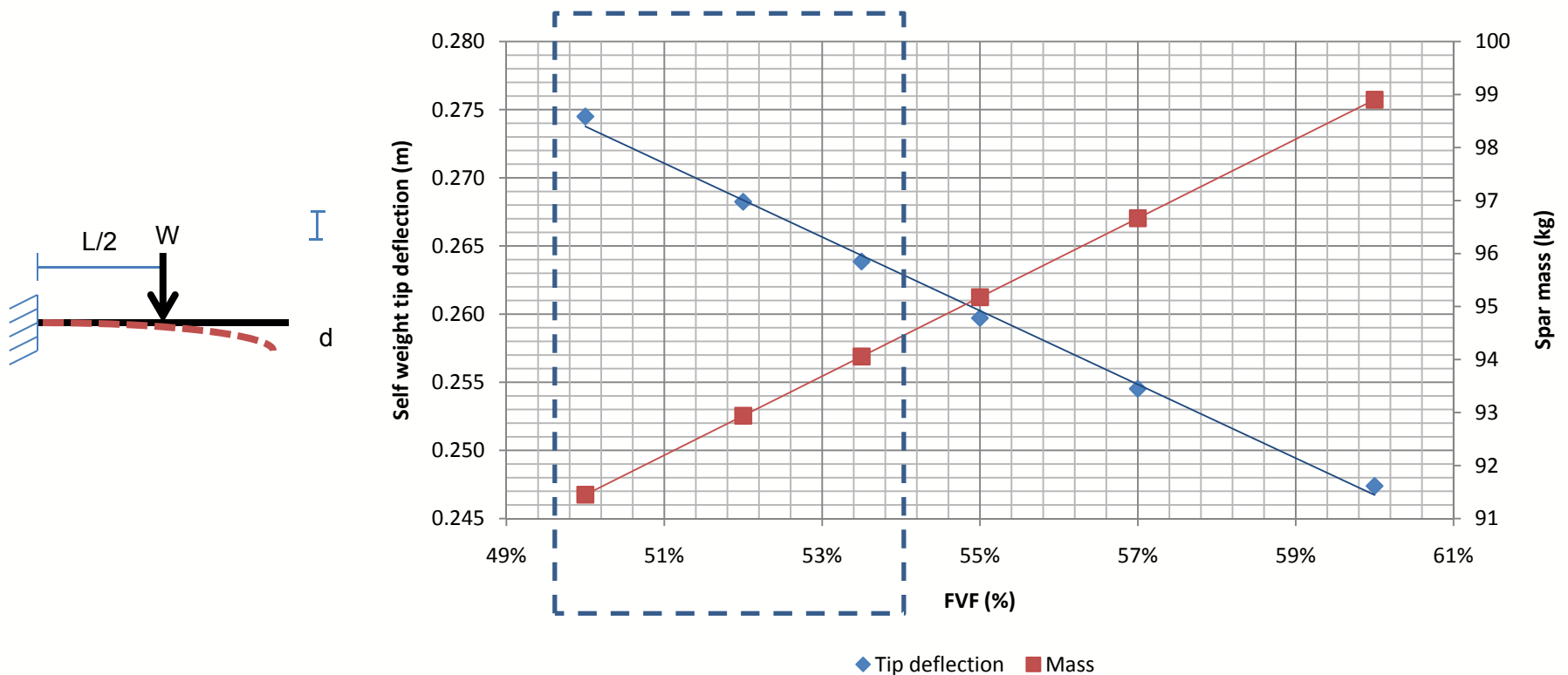


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Effect of FVF on tip deflection of spar, self weight

4. Alternatives for stronger, stiffer blades: Increase FVF

Common design space (E-glass)



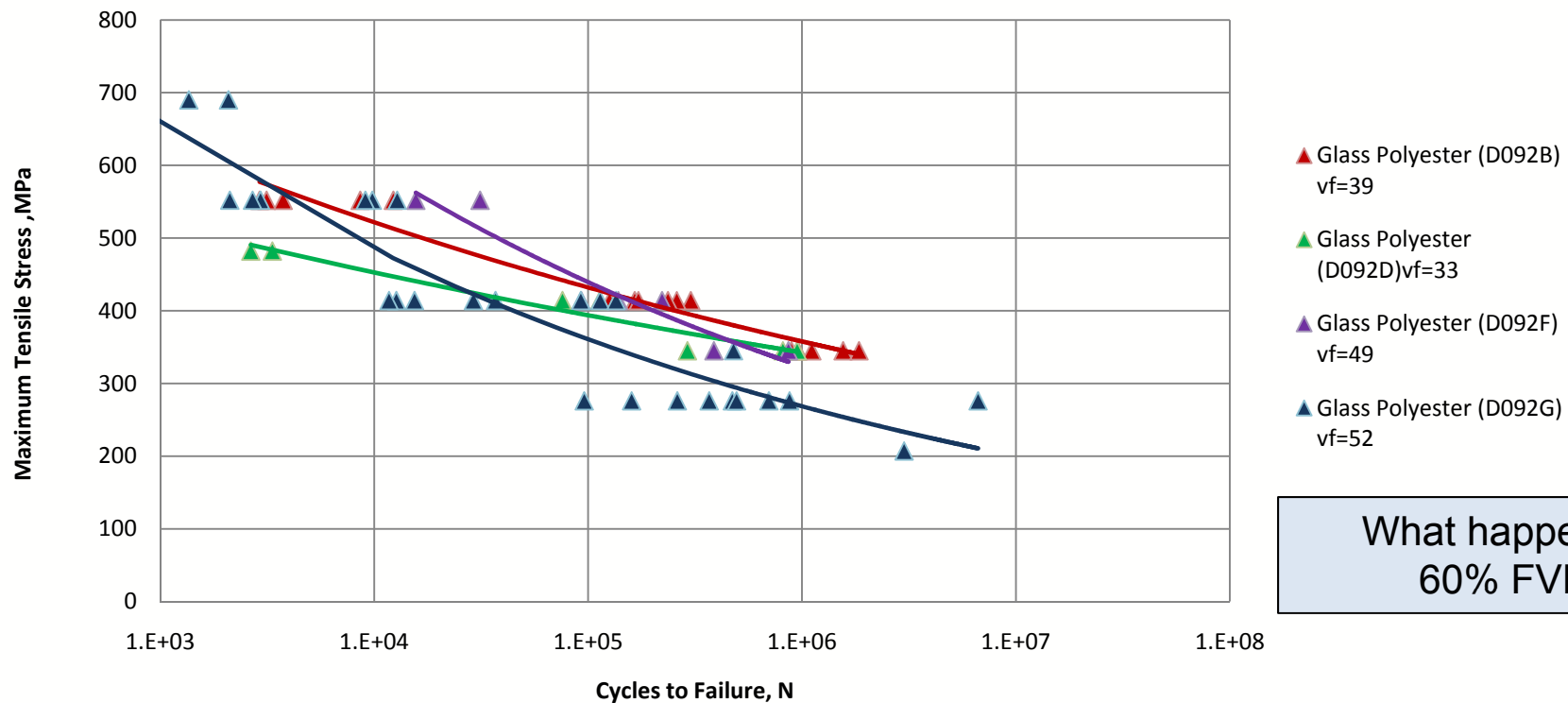


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Effect of FVF on dynamic properties

4. Alternatives for stronger, stiffer blades: Increase FVF

S-N Curve Unidirectional-Infusion



What happens at
60% FVF?



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Reinforcement Landscape - Fiber Properties

4. Alternatives for stronger, stiffer blades: Fiber Composition

Fiber Types	E glass	R glass	S glass	Carbon
Density (g/cm ³)	2.55 – 2.64	2.55	2.46 - 2.49	1.7
Young's Modulus (GPa)	70 – 77	84-86	86 – 90	220
Pristine Strength (MPa)	3450 – 3790* 2800**	4400* 3900**	4590 – 4830	3800**
Failure Strain (%)	4.5 – 4.9		5.4 – 5.8	0.7

*pristine

**impregnated strand per ASTM D2343

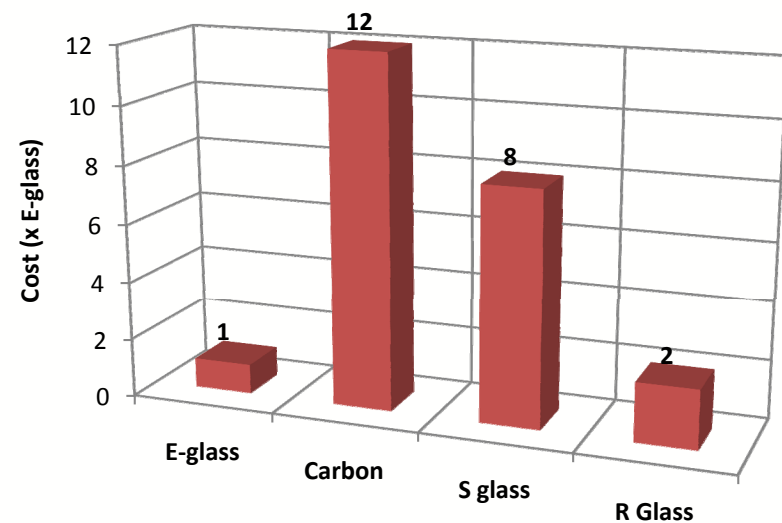
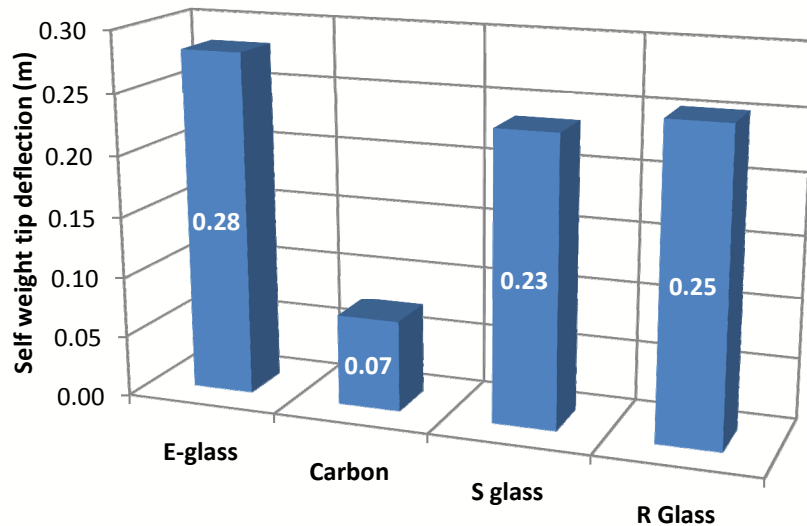


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Edge deflection on spar model

4. Alternatives for stronger, stiffer blades: Fiber Composition

As Fiber Modulus Increases, deflection is reduced but cost per lb increases...

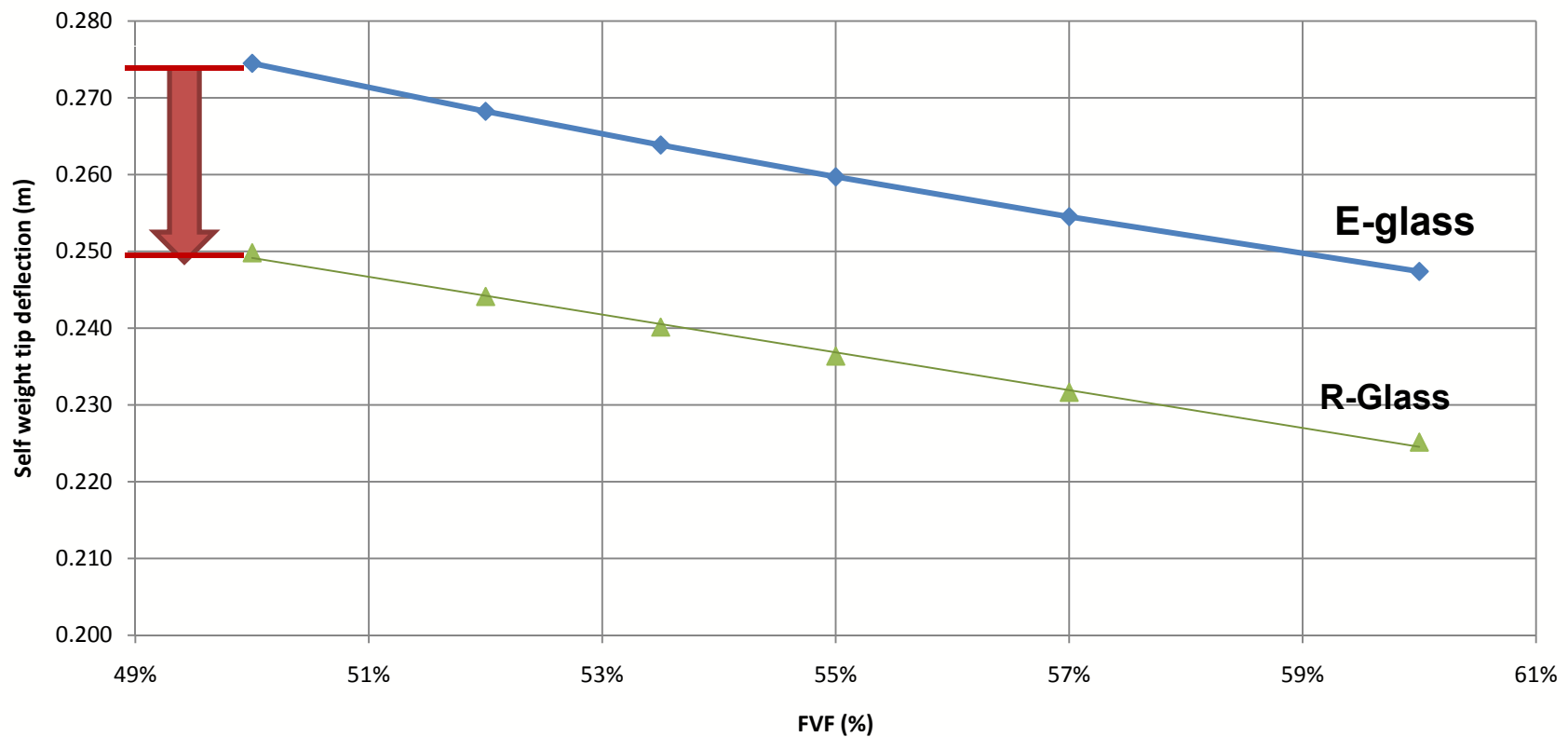




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Composition shift E to R

4. Alternatives for stronger, stiffer blades: Fiber Composition





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What is next?

5. The future state – long-term goals and new developments

- Faster, easier processing
 - Faster wet-out for liquid molding
 - Reduced probability of porosity in laminates
 - Reduced abrasion
- Defect reduction
 - Material forms adequate for FP/ATP (process driven)
 - Resin specific sizing technology (innovative film former chemistry)
 - **Higher Tensile strength**
 - **Higher SBSS and strength retention**
 - **Improved fatigue performance**



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New material forms and process development

5. The future state – long-term goals and new developments

- ATL/FP grade materials
 - Equilibrium between performance and cost
 - Material tolerances
 - Paper requirements
 - Impregnation levels and slitting characteristics
 - Tack
 - In situ consolidation

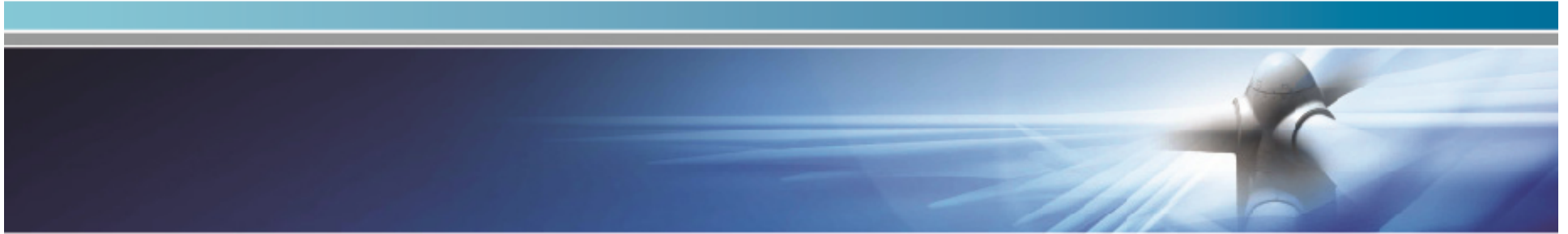




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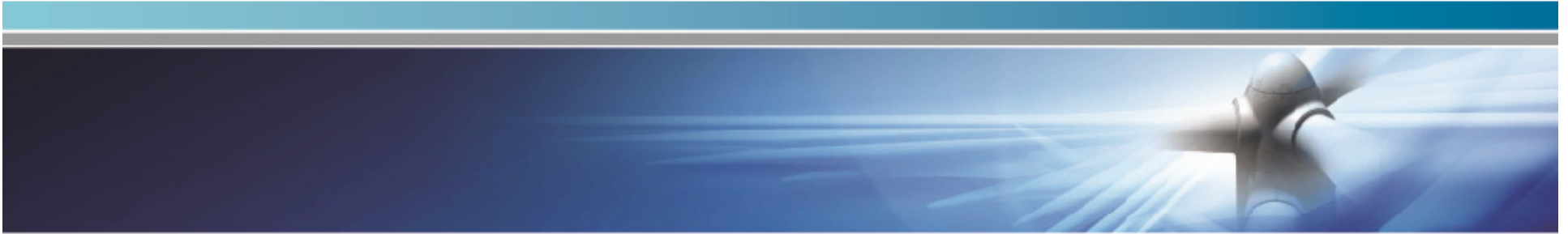
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HYBON 2026 Manufacturing Sites



Shelby



Wigan



Zibo



Chester



Lexington

